Things that Go Bump in the Night

The Physics of "False" Poltergeists

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Natural vibroacoustical phenomena that are often accredited to ghosts and other paraphysical causes are reviewed and explained. Acoustical and mechanical resonances, rattling windows and doors, the canyon effect, whispering galleries, remote noises and vibration propagation, and noise emission by structures under deformation are covered. Acoustical effects created by live ghosts (people and animals) are also discussed.

Many stories have been told of haunted houses with strange and fearful effects occurring mostly at night – mysterious noises and vibration, strange lights, moving furniture or levitating objects, and enigmatic structural damage (cracks in the walls, heavy doors exploding off the hinges, falling bookshelves or chandeliers).

Such phenomena are often attributed to poltergeists. This term combines two German words, *poltern* (to make sound or to rumble) and *geist* (ghost or spirit) and might be translated as a noisy spirit.[1,2] In Russia, a mischievous and relatively harmless poltergeist is called barabashka (in Russian, *baraban* means drum).

Poltergeists are studied by both scientists and para-scientists who believe in supernatural effects which cannot be interpreted in terms of common physics and psychology. In particular, the parapsychologists consider poltergeists as playful, often ill-behaved spirits, and admit a so-called life energy that can survive death and which might explain apparitions. On the contrary, scientists divide poltergeists in two main groups:

- Those generated by known natural effects (which may not be fully interpreted).
- Those produced by new phenomena waiting for their discoverers (in particular, ball lightning that looks like a floating ball of light resembling the legendary image of a human soul).

The physical nature of ball lightning is not clear yet, but its discovery might result in developing new sources of electrical or thermal energy. If the natural origin of a poltergeist occurrence is proven, the para-scientists call it a "false poltergeist." To prove the natural origins of a poltergeist, some scientists refer to Occam's razor, a philosophical principle stating that only the simplest explanation is valid. However, while the simplest answer is often true, it is not *always* true. One should remember Albert Einstein's warning, "Make everything as simple as possible, but not simpler," and Newton's statement, "To myself, I am only a child playing on the beach, while vast oceans of truth lie undiscovered before me."

The goal of this article is to describe the vibroacoustic effects that can produce "false" poltergeists.

Acoustical Resonance Ghosts

Roaring Ghosts of the Bottles. At the end of the 19th century, a devious contractor hired a team of workers to build a rental building in Moscow.[3] After the building had been completed, the rogue took advantage of the verbal agreement with the workers (they were illiterate) and paid them just half of what had been promised. In response to their protest, he called the police and made the workers improve the roof just for food and vodka.

However, tenants did not stay long in the new building because of a mysterious nocturnal roaring. As a result, the "haunted" house did not provide enough rental income, and creditors appeared with written contracts in hand. The contractor tried to fix the problem using illegal methods but finally went to prison.

The new owner, a railroad engineer, hired the workers who had built the house and asked them to eliminate the source of the evil noise. They showed him the empty vodka bottles revengefully embedded in the roof and loft with the open necks outward. The air in the bottles resonated and wailed when a wind blew across the open necks (Figure 1). Simulating the vodka bottle like the Helmholtz resonator, the engineer calculated the frequency of this noise as about 100 Hz. This low-frequency sound penetrated into the rooms through the ceiling and windows and was most audible at night. During the day, the roaring was masked by the street noise, and local winds were not as strong. Such a nocturnal noise, both tonal and intermittent, proved too annoying even for those tenants who did not believe in poltergeists. After the cheerful workers had removed the glass ghosts, the rental house became profitable.

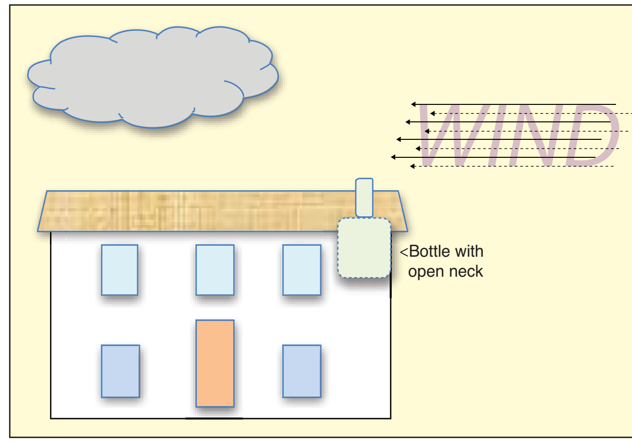

Figure 1. Air in bottles resonated and "wailed" as wind blew across open necks.

Helmholtz resonators were discovered long ago. In particular, they were used in the "whistling" arrows of the Middle Ages as signaling and intimidating warfare. The simplest Helmholtz resonator is a bottle with a narrow hole or neck. At low frequencies (if the acoustic wavelength notably exceeds the resonator's dimensions), the air in and near the neck moves like a solid mass compressing or expanding a spring (the air volume). The Helmholtz natural frequency is calculated as:

$$f_{HR} = \frac{c}{2\pi}\sqrt{\frac{S}{V\left(h + 0.8\sqrt{S}\right)}} \tag{1}$$

where $c = 340$ m/s is the sound speed in air, S and h are respectively the area and effective length of the hole or cylindrical neck, and V is the air volume inside the bottle. Such a resonance excited by the air turbulence, which was caused by the wind passing across the open bottle necks, was responsible for the false poltergeist in the Moscow house.

Helmholtz's Resonances Excited by Wind, or Infrasound in Rooms. Helmholtz's resonator excited by the turbulent airflow can generate a high acoustic pressure at its resonance frequency both inside and outside the resonator. But Helmholtz's resonator excited by an outside sound wave partly absorbs the incident sound energy and generates a high acoustic pressure just inside its body.[4] A room with an open window or door can operate as a Helmholtz resonator with a rectangular hole.[5]

Here, Helmholtz's resonance can be excited by the turbulence in the airflow passing through or across the open window or by sound waves coming from external or internal noise sources. To estimate the natural frequency of such a Helmholtz's resonator, one can use Eq. 1, even though the window is not round, because the expected error is not significant. If the room volume $V = 50$ m^3, the wall thickness $h = 0.1$ m, and the window area $S = 1$ m^2, the Helmholtz natural frequency calculates as $f_{HR} \approx 8$ Hz. That falls inside the infrasound frequency range (below 20 Hz, which is the lower limit of human hearing).

A powerful infrasound can painfully vibrate internal human organs. Such a conclusion was based mostly on the experiments of the French scientist Vladimir Gavreau who even attempted to build a low-frequency acoustic weapon after his accidental exposure to infrasound. While working in a concrete building that housed his laboratory, Gavreau and his co-workers periodically suffered from nausea. Eventually, he traced the problem to an improperly installed motor-driven ventilator activating an infrasonic resonance in the building while the building interior worked as an amplifier.

The resonance frequency of that giant amplifier could have been controlled through opening or blocking the windows. However, the ensuing experiments done by independent researchers exposed less drastic effects of infrasound on human health.[6]

Once, an infrasound generator was employed to drive rioters out of a building by connecting an infrasound generator to the ventilation ducts and running it at the resonant frequency. Therefore, infrasound resonances may create the effect of a poltergeist in rooms with fully or partly open windows. Even if the windows are locked, the role of the Helmholtz resonator neck can be played by the open doors or air-conditioning channels.

Helmholtz's Resonance Excited by Vibrating Wall. An acoustic resonance can also be excited by a vibrating wall of Helmholtz's resonator.[5] I made a small physical model – the miniature cubic "room" with the square (10 mm × 10 mm) ceramic floor and side walls, 1 mm thick (Figure 2). Two parallel sidewalls were made with a horizontal rectangular slot, 4 mm long and 1 mm wide. The silicon roof, 0.5 mm thick, incorporated a round hole filled with a circular elastomer membrane supporting a silicon disc, 3 mm in diameter. Note that Helmholtz's resonator with two similar openings is about similar to that with one opening of the same total area. Because of its miniature size, the room can operate like Helmholtz's resonator in the frequency range below 8000 Hz.

For a sine sweep test in the vertical direction, the room was fixed on a 1-DOF shaker, and the disk vibration velocity was measured using a single-point laser-vibrometer. Two spectra of the vibration transmissibility (the ratio of the amplitudes of the disk and shaker velocities) were measured: (a) for the room shown in Figure 2, and (b) for the same room but with two sidewalls removed.

As seen in Figure 3, the first spectrum reveals two peaks caused by the disk-membrane resonance at ≈2000 Hz and by the Helmholtz resonance at ≈3500 Hz. The second spectrum, measured just for comparison, contains only the disk-membrane resonance, since the room without two walls is not Helmholtz's resonator. The Helmholtz resonance peak is powerful because of relatively low dissipation of the vibration energy in air. So the Helmholtz resonance in a room can notably amplify the amplitude of the vibrating wall and develop cracks with time.

Air Volume Resonances in Rooms. The fundamental (minimal) natural frequency of the air volume in a typical rectangular room is calculated by Equation 2:

$$f_1 = \frac{c}{(2D)} \tag{2}$$

where c is the sound speed in air and D is the maximum dimension of the room.[4]

For example, if $D = 3$ m, the fundamental natural frequency calculates to about 57 Hz. A loud noise at this frequency may produce an adverse psychological effect. For the whole human history, thunderstorms were considered to be demonstrations of God's power and wrath. The maximum spectral sound components of thunder used to be in the frequency range 50-150 Hz. So the acoustic noise produced by the thunder can reverberate loudly in a small room. Such a natural effect occurring at night could be perceived to be poltergeist. As shown in Reference 7, some ancient priests used this effect by performing their ritual services in the rooms with the acoustic resonances of between 95 and 120 Hz.

Mechanical Resonance Ghosts

Rattling Excited by Low-Frequency Vibration or Infrasound. Any linear mechanical system driven by a harmonic force vibrates at the force frequency. But if the system is not linear (in particular, because of looseness), it may rattle (vibrate and resonate) at many frequencies. Commonly, rattle is a result of striking repeatedly an elastic body against a hard surface and is perceived like a rapid succession of knocking sounds.[8] Such nonlinear rattle may occur in windows if the excitation force exceeds some threshold (see Figure 4).

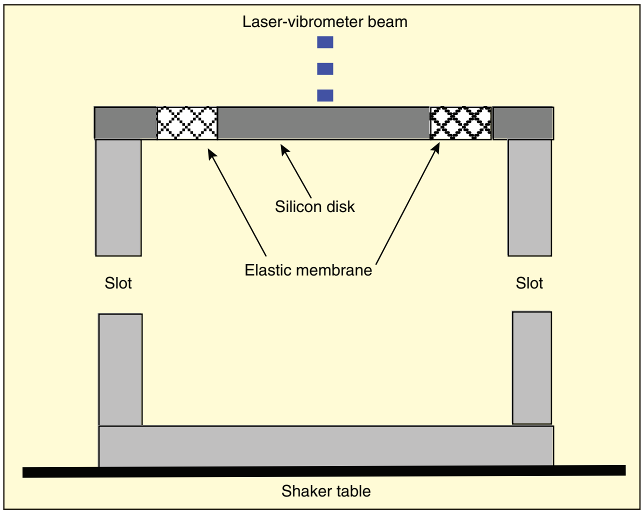

Figure 2. Test setup developed to illustrate effect of Helmholtz's resonance on amplitude of vibrating wall.

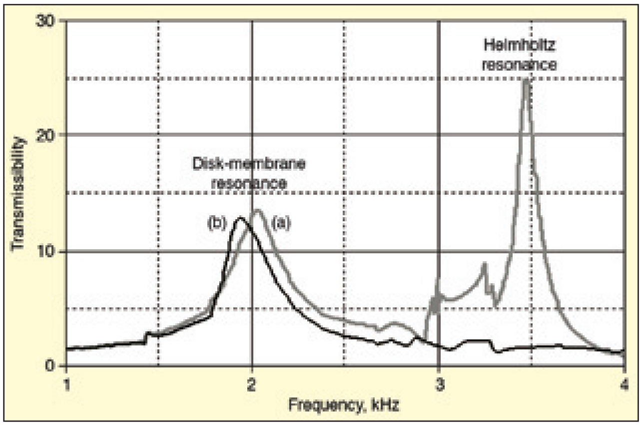

Figure 3. Vibration transmissibility spectra measured on sweep sine shaker test.

For instance, the environmental vibration can play the role of a bell ringer while the frame and pane serve as bell clapper and bell cup, respectively. If the frequency spectrum of vibrating force lies mostly in the infrasound range (below 20 Hz), the vibration source is not audible, but the natural frequencies of common panes belong to the audible acoustical range. In particular, the fundamental natural frequency of the square (1 m × 1 m) glazing, 3 mm and 9 mm thick, are about 30 and 90 Hz, respectively.

I was once invited as an acoustical consultant to a company's office where a single window (made of 9-mm panes) rattled like a ringing bell. This frightening performance happened mainly in the evenings, so, the women accountants did not like staying late even to finish urgent reports. It was a large multistory building with thick outer walls, floating floors, and high-quality hung ceilings. The company office was on the fourth floor, and the fifth and third floors were occupied by the other companies. Generally, the sound isolation was good, so, the office employees did not hear their neighbors.

I visited the company on the fifth floor and found a small gym made by local employees and used in the evenings. The gym equipment included two treadmills installed near the window. I asked two women to start running on the treadmills and went downstairs to listen, but no significant noise was revealed. I returned to the fifth floor and asked two sturdy men to run on the treadmills. This time the window on the fourth floor started ringing like a bell in horror movies. Such a spooky rattling was fully eliminated after my proposal – the fifth-floor people moved both treadmills away from the outer wall.

Vibration Caused by Technical Equipment. Notable vibration in buildings can be transmitted from technical equipment to

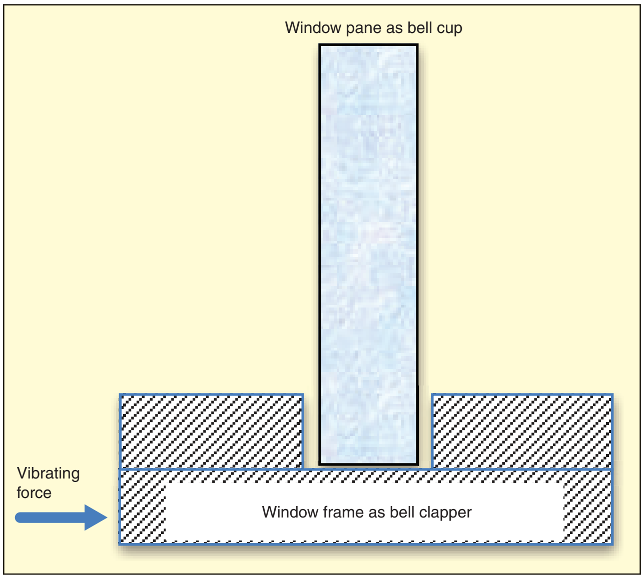

Figure 4. Rattle in window.

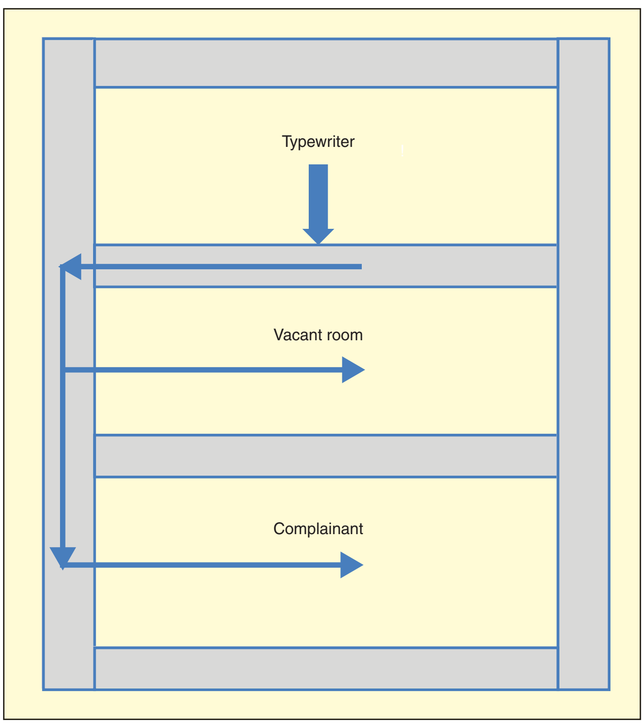

Figure 5. Typewriter as poltergeist.

windows, bookshelves, desks, and doors in the nearby rooms. That's what happened in a nine-story business building where the air-conditioning and other technical equipment was located on the ninth floor.

The equipment was vibration isolated, so its normal operation did not annoy the employees below. But almost every day the bookshelves and desks on the eight floor might rattle for about half a minute. The employees described such frightening events like weak earthquakes that happened mainly in the evenings.

An acoustical consultant found the source of rattle – a powerful fan with an elevated imbalance. Its vibration at the regular operation speed was properly controlled with its vibration isolators. The natural frequency of the 1-DOF system incorporating the fan as a mass and isolators as a spring was about 2 Hz. When switched off (commonly in the evenings), the fan gradually reduced its rotation speed to zero and a so-called "rundown resonance" occurred as the rotation speed passed 2 Hz. The effect was amplified even more because of a proximity of the rundown-resonance frequency to the fundamental natural frequency of the whole building, which was about 1 Hz. (This was estimated by rule of thumb – the fundamental frequency approximately equals 10 divided by the number of stories, nine.) After the fan was balanced, the "earthquakes" stopped, because even though the rundown-resonance vibration was not eliminated, its magnitude was significantly reduced.

Structural Sound Transmission Via Building Panels with Similar Natural Frequencies. This happened in one a multi-story, concrete-frame buildings.[1] According to an older woman living on the second floor, she heard a mysterious low-frequency noise between 9:00 a.m. and 6:00 p.m. when her third-floor neighbor was not home. The acoustical consultant decided to visit the neighbor on the fourth floor. She proved to be a typist working at home. The vibration from her mechanical typewriter conveyed through the desk to the linoleum floor, and the thin linoleum layer was not a good isolator to low-frequency vibration.

As shown in Figure 5, all the floor slabs and the internal and external walls of the building were similar concrete panels. The fundamental frequency of the bending vibration for such panels calculated to be about 60 Hz, which was consistent with the spectrum measured in the apartment on the second floor. The typist willingly agreed to have rubber isolators put under her desk, and the "ghost" problem was solved to the full satisfaction of both neighbors.

Remote Poltergeist Sources

Canyon Effect in Indented Wall of Multistory Building. A street canyon (also known as an urban canyon) is a place where the street is flanked by buildings on both parallel sides. By neglecting the sound absorption in air and on solid surfaces, the energy of a sound wave propagating in a canyon attenuates inversely to the distance from the noise source by 3 dB with every doubling of the distance. For comparison, in a free field with no sound absorption, the sound attenuation is governed by the inverse-square law, or an attenuation by 6 dB with every doubling of the distance.[10]

A similar effect occurred in a "wall canyon" (see Figure 6) formed by the outer wall of a high-rise building in Moscow.[11] Due to the canyon effect, acoustic noise spread far in the vertical direction from one open window to another. (Since there was no central air-conditioning in the building, the windows were usually open, at least in the summertime). The canyon width was $L = 6$ m, the height of the canyon flanks was $H = 2$ m, and the distance between the centers of adjacent windows was $b = 3$ m. Because of diffraction, the low-frequency sound waves propagated around the canyon flanks with no significant reflection inside the canyon, so the canyon effect occurred mostly at mid to high frequencies defined by the approximate equation:

$$f \geq f_{canyon} = \frac{c\sqrt{b^2 + L^2}}{H^2} \approx 570 Hz \tag{3}$$

where c is the speed of sound in air and the other parameters are described above.[11]

As a result, the noise traveling through the open windows from the third floor to the seventh floor lacked the original low-frequency components. It was perceived like a strange whisper or conversation that was not produced by any nearby neighbors and therefore sounded ghostly to some residents.

Whispering Galleries. A typical whispering gallery is constructed in the form of a circular wall and allows relatively effective sound perception along this wall. The effect was first interpreted by Lord Rayleigh in 1878 which explained the phenomenon of travelling whispers with a series of reflected sound rays making up chords of the circular gallery.[12]

In this case, the sound should decay in intensity only as the inverse of the distance (like in the canyon) rather than the inverse square as in the case of sound radiating in all directions. The gallery walls or ceiling may also be in the form of an ellipse, with an accessible point at each focus: when a visitor stands at one focus and whispers, the sound rays emanating from this focus reflects directly to the other focus, where the whispers can be heard. However, such effects are not of much importance now, since the shape of present-day bedrooms are rectangular.

Remote Noise Sources. Refraction is the deflection of waves when they enter a medium where their speed is different.[10] Be-

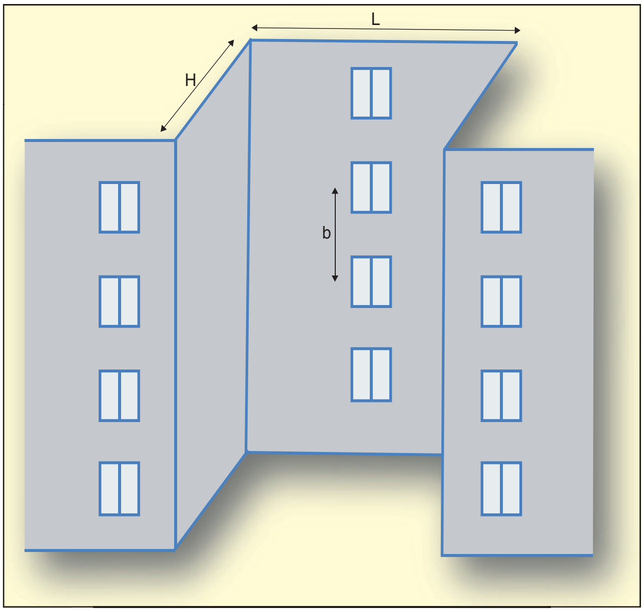

Figure 6. Wall canyon in multistory building.

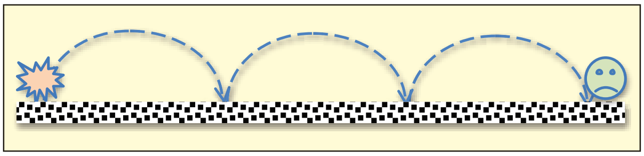

Figure 7. Distant sound propagation due to refraction during negative temperature inversion.

cause of refraction, sound wave energy might attenuate inversely to the distance even if the wave propagates in the free field. This effect can occur during a negative temperature inversion, when the temperature is coolest right next to the ground and increases with the distance above ground. Therefore, the speed of sound also increases with height, so the wave tends to change direction and bend downward. These negative temperature inversions commonly happen in the evening when the ground cools quickly and the air above remains warm. With multiple reflections from the ground, the sound wave can propagate like in a canyon for long distances as shown in Figure 7. As a result, even relatively distant sources of noise (an owl's hoot, for example) can be perceived far away during some hours of darkness.

Noise as Predictor of Structural Failure

Some ghost stories describe a suspicious noise in the residential rooms before a collapse of bookshelves, chandeliers, ceilings and even wall parts. Were "unclean" or natural forces in work there? The effect of sound emission from a stressed material may explain such occasions.

In 1971, I was a student at the Moscow Institute of Physics and Technology, and I developed a computer program to calculate the deformation of a salt layer hit by a steel plate moving at high speed. The goal was to numerically simulate the stress waves generated by underground nuclear explosions. The computed graphs clearly exposed two moving profiles:

- A high-amplitude plastic deformation wave.
- A low-amplitude elastic wave moving at a higher speed (like a harbinger of upcoming structural collapse).

This result was expected, because underground explosions and earthquakes commonly generate forerunning sound waves. In the case of earthquakes, the wavelengths are large (10-100 kilometers in order of magnitude) and belong to the infrasound range in terms of frequency. These infrasound waves may be emitted a few days before the main tremor occurs.

It has been shown that the ground vibration and infrasound radiation in air can be sensed by some animals. People have often observed the continuous restlessness of dogs, cats, birds and snakes prior to earthquakes. Acoustic emission may be a precursor of any mechanical fracture in metal and stone structures. In particular, scientists often observe a notable acoustic noise emitted in the frequency range of 100-600 Hz by a rock surface before it cracks.

In metal and concrete structures of buildings and aerospace vehicles, the stress concentration areas are mainly located near cracks in the material. Consider the typical speed of sound in building structures to be 3000 m/s. Then if the effective size of dangerous cracks is 0.03-3.0 m, the emitted sound frequencies belong to the range 1-100 kHz in order of magnitude.

The upper limit of human sound perception does not exceed 20 kHz and tends to decrease with age. For this reason, sound emission from metal structures (where the cracks are relatively small and speed of sound is relatively high – up to 5000 m/s) is not perceived by most people. But dangerous cracks in building walls may be large enough to create audible noise.

Live Ghosts

Some ghosts are natural and alive – in particular, black cats, talking birds (even if they do not live in our houses),[13] along with human strangers. The owl, for example, has a powerful voice and spooky repertoire, including a fast energetic hooting sound that can be heard for more than two miles in calm weather. In Australia, the lyrebird is capable of imitating whistles, car engines, fire alarms, rifle-shots, dogs barking, crying babies, music, mobile phone ring tones, and human voice.

One of the proverbs of Confucius, the great Chinese philosopher, states: the hardest thing of all is to find a black cat in a dark room, especially if there is no cat. But what if a stray black cat sneaked into your yard at night? This once happened to a friend who was a young soldier at the time; he happened to be guarding a military depot at night. Suddenly, he heard quiet steps close to him and shouted in the darkness: "Stop! Who is that?" Nobody replied but the steps ceased and remained silent for a few minutes.

The soldier calmed down. but the steps were heard again and even closer. He became frightened and briefly commanded, "Stop or I'll shoot!" and fired a warning shot into the air. The invisible perpetrator, who ran away through an illuminated spot of the yard, proved to be a black cat. Later the wily feline came back, but this time with a friendly meowing signal to avoid another shooting. Her goal was quite peaceful – just to check a garbage can near the dining room. This example also illustrates how sensitive our ears are at night, since cats are usually very quiet and stealthy.

In the other two case histories, the ghosts proved to be human beings. One of the single residents of Kasuya, a small town in western Japan, noticed that food had been mysteriously disappearing from his refrigerator.[14] The worried resident installed security cameras and promptly detected the culprit, a middle-aged, homeless woman who had been living on the top shelf of a closet for several months, using his food and even taking regular showers while the real owner was out. Police arrested her for trespassing. It is interesting that the owner heard no unusual noises or steps in the house. But more sensitive people in his place might have heard the presence of stranger and considered it a poltergeist.

The other case happened in a Ukrainian town about 50 years ago when I was a 10-year-old boy. Some vacant buildings remained badly damaged after World War II. I enjoyed playing with friends near one of such buildings, but the boys were afraid of a bizarre crying and whistling inside its basement in the evenings. A local hard-boiled policeman bravely moved inside the house with a lantern and gun in his hands. Very soon he came back with a frightened homeless man who lived there and created the weird noises to prevent children from visiting his hiding place. The policeman strongly recommended that the man leave this building, mainly because it was scheduled for demolition. A month later, the local poltergeist haunt was completely gone.

Conclusions

We have covered natural vibroacoustic phenomena that may create the illusion of poltergeists to some witnesses (mainly at night): acoustical and mechanical resonances, rattling windows and doors, the canyon effect, whispering galleries, remote noises and vibration propagation, and noise emission by the structures under deformation (with a potential fatigue failure upon time). The acoustical effects created by the live ghosts (people and animals) were also discussed. However, I do not pretend to explain all the poltergeist stories in the world. As said in the classical Shakespeare's play "Hamlet:" "There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy."

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