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Microwave Auditory Effects Among U.S. Government Personnel Reporting Directional Audible and Sensory Phenomena in Havana

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ABSTRACT The mysterious incidents on diplomatic and intelligence personnel began in 2016. Since then, nearly 200 incidents have been reported. The illnesses and symptoms are called Havana Syndrome, named for the city where cases were first reported. The initial accounts from Havana include hearing of loud high-pitched sounds, localizing the sources as coming from above or behind the head, experiencing a directional sound that ceases if one steps away, the covering of ears not making any difference, some hearing the sound but others in the same room not hearing it, or hearing it in one part of a room but not in other areas. Assuming the reported symptoms and accounts are consistent, the microwave auditory effect provides a scientific explanation for Havana Syndrome.

INDEX TERMS Acoustic pressure wave, auditory effect, brain injury, concussion, covert operation, Cuba, diplomates, directed energy, headache, high-power microwave, intelligence personnel, loud sound, microwave auditory effect, microwave pulse, microwave sound, personnel attacks, scientific explanation, sound attack, targeting beam, traumatic brain injury.

I. INTRODUCTION

In the Summer of 2017, media outlets began reporting on the U.S. State Department's disclosure that Havana-based U.S. diplomats were experiencing health issues [1]–[6]. Their residences were described to have been targeted with bursts of ''loud'' sounds. Diplomatic staff and family members of the U.S. and Canadian Embassies have repeatedly reported hearing loud buzzing or scraping sounds. The symptoms include headaches, severe hearing loss, ringing in the ears, nausea, and problems with balance or vertigo, and are suggestive of a connection to the inner ear apparatus within the human head.

While suspicious of a Cuban governmental role in directing the incident, U.S. officials have yet to pin down the source or found any device that potential culprits might have used. Experts consulted by media outlets and the U.S. government appear to have been baffled by it. The Cuban government has repeatedly denied any knowledge or involvement.

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The incidents are mystifying and have caused considerable distress among the foreign services staff and their families. Indeed, the events have caused many government staff to return to the U.S. with their families. The mysterious cases concerning U.S. diplomatic and intelligence personnel have continued [6], [7]. At the end of 2021, around 200 personnel have reported similar aincidents while working in places like Havana, Guangzhou, London, Moscow, Vienna, and Washington, D.C. The illnesses and range of symptoms have been called Havana Syndrome after the place where cases were first reported [8].

Many potential causes were proposed. A systematic assessment of each of these speculations suggest that most of the hypothesized causes are easily dismissed. If the reported accounts are consistent, the microwave auditory effect provides a scientific explanation for the Havana syndrome. Pulsed microwaves can create an acoustic pressure wave inside the head, remotely [9]–[11]. It is plausible that the loud buzzing, burst of sound, or pressure sensation could have been covertly delivered using a directed beam of high-power pulsed microwave radiation.

II. ACCOUNTS FROM HAVANA

The initially reported accounts from Havana include persons hearing loud high-pitched sound, localizing the sources of sound as coming from above or behind their heads, experiencing a directional sound that ceases if one steps away and reappears upon returning to the same position, covering their ears not making any difference, some individuals hearing the sound but others in the same room not hearing it or hearing it in one part of a room but not in other areas. A wide array of potential causes was suggested which includes flu, tropical disease, insect pesticide, crickets, ultrasound, or psychosomatic mass hysteria.

A brief assessment of each of these suggested causes indicates flu, tropical disease, and pesticide are easily dismissed by the fact that only distinctive individuals in each incident were affected but not others in the same room or confined space. Loud sounds from crickets should be noticeable by all those who are present in the same environment. Ultrasonic waves are beyond the hearing range of humans. Also, ultrasounds propagate poorly and are quickly attenuated in air. However, it is possible that mixing of two beams of ultrasonic waves in air could in principle, generate a difference beating frequency which may produce sound in the audible range. But it is usually a weak secondary effect, and the resulting sounds would not be "loud," as reported. Thus, a rational or scientific process of elimination would preclude any of the above causes. It is noteworthy that none of the accounts mentioned any warming or heating sensation. Lastly, a psychosomatic mass hysteria response without any reported sound perception would likely be an incident different from the microwave auditory effect.

Instead, the reported accounts suggest the microwave auditory effect may provide a scientific explanation for the Havana syndrome. Pulsed microwaves can create an acoustic pressure wave inside the head. It is plausible that the loud buzzing, burst of sound, or pressure sensation could have been remotely delivered using a directed beam of pulsed high-power microwave radiation. Microwave induced sound doesn't go through the external ear; it goes directly from the brain tissue to the cochlea.

Absorption of short (μs, microsecond wide) pulses of microwave energy by brain tissues is known to create a rapid elastic expansion of brain matter and launches an acoustic wave of pressure (sound wave) that travels inside the head to the inner ear [9]–[11]. Once there, it activates the hair-cell neuronal sensors in the cochlea, which then relays the neural signal to the central auditory system for sound perception, via the same central process involved in normal hearing. A brief burst of the short high-power microwave pulses cannot be felt as heat, or generate measurable temperature rise in any biological tissue. Thus, the hypothesis of microwave auditory effect is supported by numerous published laboratory and theoretical research.

Depending on the power density of the impinging microwave pulses, the level of induced sound pressure could be considerably above the threshold of auditory perception at the cochlea—approaching or exceeding levels of discomfort (including the reported headaches, ringing in the ears, nausea, and problems with balance or vertigo), and even causing potential brain tissue injury.

III. CLINICAL FINDINGS

Clinical radiological examinations reported symptoms that resemble mild traumatic brain injury (or concussion). Compared to individuals not experiencing the loud bursts of sound, brain magnetic resonance imaging (MRI) revealed significant differences in whole brain white matter distribution and volume, regional gray and white matter volumes, cerebellar tissue microstructural integrity, and functional connectivity in the auditory and visuospatial subnetworks but not in the executive control subnetwork [11]–[14]. However, the clinical importance of these differences is not definitive. A high-power microwave pulse-generated acoustic pressure wave can be initiated in the brain and then reverberate inside the head and potentially reinforce the initial acoustic pressure causing injury of brain matters.

While the clinical symptoms presented are concussion-like, the MRI images did not resemble usual presentations of traumatic brain injury or concussion. However, clinical experiences with concussion are mostly derived from externally inflicted impact injuries such as a hit to the head against the ground or other rigid bodies, which may set brain tissues into violent motion against the skull. A high- power microwave-pulse generated acoustic pressure wave could be initiated in the brain and then reverberate inside the head (see results of computer simulations in [8], [10]) and potentially reinforce the initial pressure to cause injury of brain matter. Thus, it is conceivable that the MRI images from high-power microwave-induced pressure or shock waves may have entirely different manifestations of the brain injury or concussion. The clinical importance of these differences is uncertain at present and undoubtedly demands further study for clarification.

A recent case report discussed a 43-year-old male with presumed directed microwave exposure, while under Department of State assignment in Guangzhou. The patient developed progressively worsening headaches, dizziness, auditory/vestibular symptoms, balance problems, difficulty sleeping, and cognitive/emotional complaints [15]. The publication outlined the physical therapy care and provided ideas that might benefit future diplomats and government employees who experience problems after suspected directed microwave energy exposure. More than two years after exposure to Havana Syndrome, the patient remains symptomatic but is much improved compared to when he was medically evacuated to the U.S. He continues to report fatigue plus ocular and vestibular issues. It was suggested that the episodic nature of his vestibular rehabilitation care may have resulted in suboptimal outcomes.

The U.S. National Academies of Sciences, Engineering, and Medicine released its study report [6], which examined the possible causes of the described illnesses. It made the point that among the mechanisms the study committee considered, the most plausible mechanism to explain these cases, especially in individuals with distinct early symptoms, appears to be directed, pulsed microwave energy [5], [6]. U.S. government has authorized compensation to victims of this mysterious affliction [16] and indicated that it is vigorously investigating the latest reports of the mysterious illness affecting American diplomats and intelligence personnel [17].

IV. RECORDING "MICROWAVE SOUND"

Several recordings of sound associated with what some U.S. Embassy staff heard in Havana have been released [18], [19]. Would the ''microwave sound'' show up on an acoustic-recording instrument? The answer is that it would depend on the design and fabrication of the sound sensing device. A typical sound recording device would not be able to record the microwave sound because it is generated inside the subject's head. This includes any commercially available cellular mobile telephone. On the contrary, if it was easy to record the sound with a typical sound recording device, most persons in the same room or environment should be able to hear the loud sound. The Havana syndrome then would likely not be a mystery.

Note that the initial reports of persons hearing loud high-pitched sound and distinct tones that sounded like nails-colliding-on-the-chalkboard effect are significant. The center or fundamental frequency of microwave auditory effect in humans is known to be around 8 kHz, which is regarded as high-frequency sounds in most people with normal hearing acuity. The range for perfect hearing in humans is between a few Hz up to 20 kHz; but very few people hear the higher range. Furthermore, the hearing of wider microwave pulse-induced sounds has been reported as knocking sounds [10], [11]. Depending on modulation and pulse width, different microwave pulses or pulse sequences will generate different sound sensations via microwave auditory effect.

V. MECHANISM AND THRESHOLDS

The hypothesis of microwave auditory effect for the Havana syndrome is based on results from numerous laboratory investigations and theoretical research, and supported by biological, physical, mathematical, and computer simulations along with reported experiences of the embassy staff. A recent review [10] showed that the mechanism for the microwave auditory effect arises from miniscule but rapid (μs) rise of temperature (10^{-6} °C) in the brain from absorption of high-power pulsed microwave radiation in the μs-pulse width range. The sudden but miniscule rise in temperature creates elastic expansion of the brain matter, which can launch a sonic pressure wave that propagates through the head and is detected by the sensory neuronal hair cells of the cochlea in the inner ear, bypassing the external ear. The nerve signal is then relayed to the central auditory system for perception and recognition at the cerebral auditory cortex.

Depending on the power density of the impinging microwave pulses, the level of induced sound pressure could be considerably above the threshold of auditory perception at the cochlea—approaching or exceeding levels of discomfort (including the reported headaches, ringing in the ears, nausea, and problems with balance or vertigo) and even causing potential brain tissue injury. The near-zone thresholds determined under controlled laboratory conditions for peak microwave power density of auditory perception in human subjects with normal hearing are given in Table 1. While there are variations in measured threshold values over the range of 1 to 70 μs of pulse widths involved, the subset of data for 10 to 32 μs fall within a narrower range. Considering that the ambient noise levels in all three experiments were essentially the same, it is reasonable to conclude that 14 kW/m^2, the average threshold power densities of 2.1 to 40 kW/m^2, as a threshold peak power density for induction of the microwave auditory effect in the near field of 1250 to 3000 MHz microwaves with pulse widths between 10 and 30 μs.

(Note that the units of measure of kW/m^2 or GW/m^2 per pulse refers to power per square meter-power density, not the total output power of any source.)

In other words, the 14 (2-40) kW/m^2 per pulse peak power density generates a barely audible sound level of 0 dB re 20 μPa [10], [11]. Generating sound at 60 dB (20 mPa), or the traditional audible level for normal conversation, requires 1000-fold higher power density per pulse. Generating tissue injuring level of sound at 120 dB (20 Pa) would take another 1000-fold increase in required peak power density, or 14 (2–40) GHz per pulse. Typically, damage or adverse effects on auditory pathway and audiovestibular systems would occur at far lower peak power densities than injury to brain tissues by two orders of magnitude or more.

It is noteworthy that at a sound pressure level of 120 dB, the corresponding theoretical temperature elevation would be less than 1°C, a temperature elevation which is considered ''safe'' by the currently promulgated exposure protection guidelines or safety standards [20], [21].

TABLE 1. Thresholds of microwave induced auditory sensation in adult humans with normal hearing determined in controlled laboratory studies. (*Typical SPL for microwave anechoic chambers lined with absorbing materials; ** with plastic foam earmuffs).

Frequency (MHz)	Pulse Width (μs)	Peak Power Density (kW/m^2)	Ambient Noise Level (dB)
1245	10-70	0.9 - 6.3	45*
2450	1-32	12.5-400	45
3000	10-15	2.25-20	45**
For 10 to 32 μs Wide Pulses			
1245	10-30	2.1 - 6.3	45*
2450	10-32	12.5-40	45
3000	10-15	2.25-20	45**

For plane wave equivalent exposures, the available computations provide two sets of data that are suitable for comparison with the results described above. In one case, the reported threshold peak incident power density for an anatomical head model is 3 kW/m^2 for 20-μs pulses at 915 MHz [22]. For the other, the threshold is about 50 kW/m^2 for 20-μs pulses at 2450 MHz [23]. The corresponding peak incident power densities at the 120 dB injury level are therefore between 3 and 50 GW/m^2 per pulse, which is within the range of above calculation for near-zone exposures. These peak power densities are close to and encompass the 23.8 GW/m^2 value for dielectric breakdown of air [11]. As the dielectric permittivity of all biological and physical materials is greater than that of air or free space, the intrinsic impedances are always smaller than that of air. The breakdown peak power density in skin, muscle, and brain tissues, for example, would be a factor of 6 higher or 142 GW/m^2 for a microwave pulse at 1000 to 3000 MHz. Thus, if the microwave auditory effect is involved, at sufficiently high powers, it is likely for the microwave pulses to cause brain tissue injury or auditory pathway and audiovestibular damage by the reverberating sonic shock waves. It would not be by microwave pulse-induced hyperthermia through excessive temperature elevation in the brain, nor by dielectric breakdown of brain, muscle, or skin tissues.

A recent computer simulation of microwave auditory effect in an anatomical human head used the same approach employed in previous numerical studies [22]–[24]. The computer simulation study showed that for 1-GHz high-power microwave pulse exposures substantial acoustic pressure may occur within the brain that may have implications for neuropathological consequences [25]. The simulation results were compared to previously established mechanically induced injury pressure thresholds for strain and stress associated with traumatic brain injury. Table 2 shows the microwave exposures required are 0.01 and 0.015 GW/m^2 of peak power density for a 5-μs, 1-GHz pulse to reach the same threshold pressures of 10 and 20 kPa, respectively for explosive blast brain and football head impact injuries. However, the peak power density needed for cavitation of brain tissue (tensile pressure) is an order of magnitude higher.

Although the required peak power densities are high, they are achievable with existing high-power commercial and military microwave systems operating under pulsed conditions [25]. Significantly, they also fall within the permissible ''safe'' limits of currently promulgated safety standards and protection guidelines, The required microwave technology is mature and in general, commercially available in many developed countries. confirming the conclusion of earlier studies.

Furthermore, the study showed that to generate tissue injuring level of high-power microwave induced acoustic pressures inside the human brain, the theoretical microwave pulse induced temperature elevation would be substantially below 1^{o}C (see Table 2), which is again ''safe'' according to currently promulgated RF and microwave safety protection guidelines.

TABLE 2. Microwave pulse-induced pressure in brain for microwave auditory effect and mechanically produced pressure [25].

Anatomy	Required Power Density (GW/m^2)	Pressure (kPa)
Explosive Blast Brain Injury	0.01	10
Football Head Impact Concussion	0.015	20
Cavitation	0.1	20-100* 467**
Frequency (1-3 GHz)	Pulse Width (0.5 -30 µs)	$\Delta T < 0.001$ ^{o}C

*Tensile pressure in brain tissue
**The 50% probability of cavitation for cerebral spinal fluid in vitro [26]

TABLE 3. Microwave pulse-induced pressure in brain for microwave auditory effect and dielectric breakdown power density [11].

Anatomy (Model)	Required Power Density (GW/m^2)	Pressure (kPa)
Cochlear Damage	2 (14)	15.4
Brain Sphere	1	60
Anatomic Brain	1	43
Frequency (1-3 GHz)	Pulse Width (0.5 -30 µs)	$\Delta T < 1$ ^{o}C
Air Breakdown	23.8	
Tissue Breakdown	142	

VI. DISCUSSION AND CONCLUSION

The results presented in Tables 1 and 2 showed that high-power microwave pulse exposure can generate substantial acoustic pressures in the brain that may not only produce sound sensations but also have implications for neuropathological consequences such as traumatic brain injury. Calculations shown in Table 3, based on traditional accepted threshold for sound-induced hearing loss due to damages to auditory sensors (hair cells) in the cochlea, indicate comparable peak pulse power densities given the wide range of variabilities. Furthermore, the computer simulated pressure results are analogous to previously established mechanically induced injury pressure thresholds for strain and stress associated with traumatic brain injury given in Table 2.

Assuming the reported accounts are consistent, the microwave auditory effect provides a scientific explanation for Havana Syndrome. Pulsed microwaves can create an acoustic pressure wave inside the head. It is plausible that the loud sound or pressure sensation could have been covertly delivered using a directed beam of high-power pulsed microwave radiation. The microwave auditory effect does not go through the external ear; it goes directly from the brain tissue to the inner ear cochlear receptors. Absorption of short pulses of microwave energy by brain tissues creates a rapid elastic expansion of brain matter and launches an acoustic wave of pressure (sound wave) that travels inside the head to the inner ear. A brief burst of the short high-power microwave pulses cannot be felt as heat or generate measurable temperature rise in any biological tissue. Depending on the power density of the impinging microwave pulses, the level of induced sound pressure in the brain could be considerably above the threshold of auditory perception. They may approach or exceed levels of discomfort or cause brain tissue injury. A high-power microwave pulse-induced acoustic pressure wave initiated in the brain and reverberating inside the head could bolster the initial pressure to cause injury of brain matters or auditory pathway and audiovestibular damage. It would not be by microwave pulse-induced hyperthermia through excessive temperature elevation in the brain, nor by dielectric breakdown of brain, muscle, or skin tissues.

The required microwave technology is mature and in general, commercially available in many developed countries. Longer distances and higher power scenarios would require more bulky equipment and sophisticated aiming devices, but packable equipment is possible for closer range nonlethal applications. This would not preclude the use of a much higher power microwave sources located more remotely from the intended targets to raise the auditory sensation to the "discomfort" levels. Also, existing hardware could be optimized to meet some specific requirements in covert or finely targeted operations.

However, it is noted that until the truth is revealed by catching the culprit(s) in the act, Havana Syndrome would remain a mystery. However, since the technology involved is established and the required equipment and components are commercially available, it is possible that some enterprises around the world are engaged in the development of such equipment, if not already installed them.

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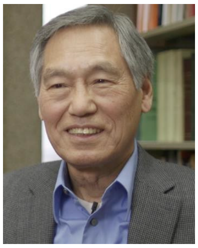

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