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Review Article

Assessing Anomalous Health Incidents of "Havana Syndrome": Potential Utility - and Issues - of Using Modular Integrated Artificial Intelligence

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Abstract

Havana Syndrome refers to a constellation of neuropsychiatric signs and symptoms that have been classified as anomalous health incidents (AHIs). First reported by personnel working at the US Embassy in Havana, Cuba, in 2016, presentation includes sudden-onset vertigo, feeling of pressure in the head, cognitive dysfunction, tinnitus, autonomic disturbances, and postural instability. It is now widely accepted that directed energy exposure is the most probable cause. The diagnostic process for Havana Syndrome AHIs remains complex and multifactorial, and herein we propose that the use of modular artificial intelligence approaches, particularly those leveraging machine learning and predictive analytics, can integrate multidimensional data from a standardized evaluative protocol employing neuroimaging, cognitive testing, auditory/vestibular assessments, and biomarker analyses to more accurately, effectively and efficiently identify patterns indicative of AHI.

We opine that such use of AI with standardized diagnostic protocols would mitigate variability across cases and institutions, and would ensure ethical integrity in patient care. However, we note that the integration of AI necessitates stringent biocybersecurity measures to protect sensitive patient data from potential breaches, and propose methods toward sustaining safety and integrity when employing these methods.

Keywords: *Havana Syndrome; Anomalous Health Incidents; Neurocognitive Assessment; Artificial Intelligence; Neuroethics*

Havana syndrome: Historical context and theories of causation

Havana Syndrome is a term used to describe a constellation of neurological and neuropsychiatric symptoms (i.e. anomalous health incidents; AHIs) first reported by United States (US) and Canadian diplomats and intelligence personnel in Havana, Cuba, in 2016. Affected individuals reported sudden-onset vertigo/dizziness, headaches, tinnitus, cognitive dysfunction, changes in visual and auditory sensation, and, in some cases, postural instability, sleep disruption, and cardiac and gastrointestinal disturbances. Over time, similar reports emerged from diplomatic and intelligence personnel stationed in China, Russia, Europe, and Washington, D.C., raising concerns that these events were indicative of an external, potentially weaponized source of insult to the nervous system.

The first cases of Havana Syndrome were reported by US personnel in late 2016, with individuals describing acute auditory and sensory disturbances preceding the onset of symptoms. Following on-site initial medical evaluation in Havana, Cuba, affected individuals were triaged to the US for more detailed assessment and diagnosis, towards receiving appropriate interventional care. Comprehensive clinical evaluation entailed a number of objective tests of vestibular function, inclusive of evaluations of saccadic function, optokinetic tracking, vestibular reflex dynamics, pupillary response, ocular convergence; and evaluations of fine and gross neuromotor functions, and multifocal evaluation of cognitive capabilities, inclusive of cognitive task focusing, vigilance, short, intermediate, and long-term (episodic and procedural) memory, and various aspects of executive function [1].

Early hypotheses suggested the involvement of directed energy exposure, specifically from sonic and/or microwave sources, possibly deployed as a form of intelligence disruption or harassment [2-4]. Other proposed etiologies have included prior or current co-morbidities, environmental toxins, infectious agents, or mass psychogenic illness; however, these have been subsequently negated due to lack of evidence [5]. Research conducted by several sources, including our group, as corroborated by the National Academies of Sciences, Engineering, and Medicine in 2020, concluded that "pulsed directed energy" was the most plausible mechanism, based on the readiness, availability, and operational viability of extant technologies, circumstantial and situational factor analyses, patterns of exposure and reported effects, and the clinical signs presented by affected individuals [6].

Yet, it is noteworthy that the subsequent media attention (and instances of relative miscommunication) has incurred a large-scale socio- and psychogenic influence. This has resulted in well over 1000 reports of individuals who believe they have been exposed to some source of pathogenic agent to date. In the overwhelming majority (> 99%) of these cases, reporting individuals have been found to have either excessive consternation regarding their overall health presentation (i.e. the "worried well" phenomena, or hypochondriasis); and/or a pre- or co-existing medical condition, inclusive of psychological/psychiatric underlay or overlay as the contributory factor [5]. It is critical that subsequent cases of these sorts should not be conflated with those individuals who were directly affected in Havana in 2016 [7]. This will be increasingly important as (1) new cases are reported; (2) current and future presentations may - and likely will - vary based upon differing conditions of presumed exposure, and individual physiological variables; and (3) there is likelihood of iterative development in the techniques and tools employed to render these injuries.

However, given that true AHI presents as a constellation of objective signs and subjective symptoms, and situational factors supporting genuine exposure to some form of directed energy can be diverse, we argue that dis-ambiguation of veritable AHI of this sort will require evaluation that entails a broader and deeper examination of each patient's history (i.e. metadata), detailed medical record, full range of physiological assessment(s), and integration of these (individual) data with a wider capture of information relevant to occupational variables that could be useful for establishing probability of risk of exposure. Toward these ends, we opine that it will be vital that ongoing assessment(s) of such reported cases employ enhanced methods for differential diagnosis, as pursuant to prompt, and effective care.

Medical evaluation and assessment protocols: A role for AI?

Diagnosing Havana syndrome requires a multifaceted approach integrating neurology, neuropsychiatry, and otolaryngology assessments. Initial clinical evaluation involves comprehensive history-taking, with a focus on the sudden onset of neurological symptoms and potential exposure to environmental stimuli [1]. Characteristically, medical assessments include:

1. **Neuroimaging:** Magnetic resonance imaging (MRI), including diffusion tensor imaging (DTI), has been employed to detect potential structural and (perhaps more importantly) functional changes in the brain. Some affected individuals have exhibited subtle white matter changes, although findings remain variable, based upon a host of factors (including time elapsed between presumed exposure and neuroimaging; duration, frequency and physical dynamics of the presumed exposure; individual phenotype; etc.).

2. **Neurocognitive testing:** Evaluations such as the Montreal cognitive assessment (MoCA) and more detailed neuropsychological batteries assess deficits in memory, executive function, and processing speed. Patients with Havana Syndrome AHI often exhibit cognitive dysfunction similar to mild traumatic brain injury (mTBI).
3. **Auditory and vestibular assessments:** Given reports of tinnitus, dizziness, and balance issues, comprehensive audiologic and vestibular testing-including videonystagmography (VNG) and posturography-are conducted to assess potential inner ear dysfunction.
4. **Autonomic function testing:** Some individuals demonstrate dysautonomic symptoms, such as orthostatic intolerance, warranting tilt-table testing and heart rate variability assessments.
5. **Biomarker analysis:** While no specific biomarkers for Havana Syndrome AHIs have been identified, research is ongoing into neuroinflammatory markers, blood-brain barrier integrity assessments, and advanced neurophysiological testing to elucidate potential pathophysiological mechanisms.

Despite extensive investigation, diagnostic criteria continue to evolve. We propose that a core battery of medical examinations should be formalized and standardized for use in assessing, discerning and differentially diagnosing such AHIs if and when any case is reported, presents for care, and is reviewed. Such standards will enable uniformity of assessment and diagnostic criteria, which we believe will make this process far more homogeneous, effective and efficient. Toward improving effectiveness and efficiency, we further opine that applications of artificial intelligence (AI) may prove to be viable and of value to this diagnostic paradigm, as supported by its utility as a reliable tool in several medical applications, including predictive analytics.

Predictive analytics combine historical data patterns, data distribution, and other patterns of patient-relevant information to derive assessment, intervention, and outcomes' prediction for target scenarios. Natural Language Processing combined with predictive analytics can be utilized to explore the potential use of AI screening to predict sign and symptom constellations in certain neurocognitive conditions. Traditionally, such diagnoses have relied on clinical interviews, self-report questionnaires, observation-based assessments, and input from family members or caregivers [8]. However, these methods have limitations regarding subjectivity and reliance on retrospective reporting. When used with ethical prudence, AI-based techniques establish a viable vector for engaging multidimensional data (e.g. biomarkers, imaging; genetics; behavioral indices, and subjective reports of cognition and emotion) to fortify diagnostic accuracy through objective analysis based on large-scale data processing capabilities [9,10].

A recent study by Wang., *et al*. [11] evaluated the application of machine learning algorithms in defining anomalous changes in cognitive state using large-scale electronic health record (EHR) data including clinical notes. Using voice recordings during therapy sessions, social media, and wearable sensor information with Natural Language Processing (NLP) sentiment analysis combined with deep projective models (i.e. paradigms trained with extensive information gathered from individuals diagnosed with representative pathology) demonstrated positive identification of subtle changes indicative of impending changes in cognitive and emotional state. The integration of such systems within the established methods of AHI evaluation may be more broadly valid, viable and valuable as AI capabilities are expanded. Herein, we describe and discuss some possible venues for AI-based assessment of AHI, which may be of use to optimize diagnostic effectiveness and efficiency.

Modular AI

Modular AI is an iterative software design that provides solutions to intricate queries by serial parsing of tasks into smaller components by using multiple individual systems (modules) in coordination, so as to not overtax the system in its entirety. Each modular subsystem is responsible for a specific function or task to enhance flexibility and scalability, thereby enabling more data to be collected and analyzed with consistent accuracy [12]. Predictive models could be integrated within a Modular AI to provide clinicians with information needed to identify sentinel factors in cognitive, emotional, behavioral and physiological functions in real time [13].

Such software requires understanding of specific tools necessary for screening patients, and the types of data collected. Integration modules process differing types of longitudinal data to account for multidimensional variables in and across temporal and environmental conditions to determine valid patterns. As defined by Sarker [14], longitudinal data analytics engage and analyze data with repeated measurements at limited time points using differing variables (behavior, physiological functions, etc.). Specific tasks integrated within individual longitudinal data systems can be incorporated within Modular AI to complete smaller tasks (collecting, storing, and analyzing data) to create a predictive model. Longitudinal data systems that could be utilized within the proposed modular AI include dynamic Bayesian networks (DBN), temporal convolutional networks (TCN), and recurrent neural networks (RNN).

Dynamic Bayesian networks are valuable for quantifying data, and reasoning about uncertainty. A Bayesian network represents individual scattered variables - and directed links between them - to represent dependencies between the variables [15]. In the context of Modular AI, a DBN could identify variations in users' physiologic and behavioral repertoires to define and/or predict patterns that may be indicative of AHI and its manifestations, and this may prove to be of value to identify changes in behavior pattern (via integration with other forms of longitudinal data). As well, DBNs can modify system nodes over the course of a task to maximize efficiency and effectiveness of pattern recognition [16]. Additionally, longitudinal data could be further analyzed by a temporal convolutional network (TCN). TCNs analyze data that are temporally collected, to assess all (forms of) variables that have been collected, to coordinate data definition and discernment along distinct (temporal and contingent parameters [17].

Recurrent neural networks (RNNs) enable connections between data via integration of NLP to effectively create a memory of previous inputs to make sense of users' speech patterns through analyses of diction, tone, and temporality [18]. Unlike TCNs, RNNs analyze prior data in a step-fashion, to correlate changes in speech during a defined temporal period/episode [19], and in this way could be used to assess and predict changes in cognition and behavior indicative of pathologic exacerbation. Each and all of these tools can be used with individuals' EHR to enable yoking of current information obtained to personal health information (PHI), inclusive of medical history, prior tests, treatments, etc. Evidently, if used for clinical diagnostic and treatment purposes, information must be de-anonymized (to enable personalization for each individual patient); and this necessity establishes requirements for all deep data dives, data capture, multidimensional analytics and deliverable findings/results to be protected against purloinment [20].

Clearly, given the need for assessment and diagnosis of AHIs for both (1) appropriate care of those affected; and (2) establishing an information repository vital for developing improved means of detection, deterrence and defense against such events, the accuracy and protection of these data are essential. Thus, these systems should entail integrity and fail-safe mechanisms within their architectures and functions to insulate data collection and analyses against data leaks and/or corruption. Kaur, Gabrijelcic and Klobucar [21] reviewed literature on programmable security mechanisms within Modular AI systems with strict access controls and data flow protocols, and concluded that such controls within individual models provide layered protection to prevent data from being (1) accessed by broad groups, and (2) used without consent.

Although data leaks could be mitigated, if not prevented, via employment of defined encryption techniques, system monitoring is essential in fortifying and sustaining data protection. Constant monitoring of such multi-modal AI systems can enable efficient identification of suspicious activity or unauthorized breaches [22]; and suspected breaches in this type of system analytics can be identified by hardware interrupts, which isolate a system breach and halt the processing program cycle until the problem is verified, addressed and/or rectified, without disrupting the integrity of analytic algorithm [23]. With each AI module connecting to the EHR, failure or corruption of one AI system will tend not to affect others, and data can be preserved through system cooperativity. To assure that data transfer within and between (AI) modules is secure, limited memory methods may be employed to transit information out of the database once a system has completed the specified analytic and integration tasks [24].

The need for systemic - and systematic - biocybersecurity

We have argued for increased stringency of all tools, techniques, protocols, and paradigms (i.e. systems and systematics) of biodata acquisition, storage, distribution, analyses and use [22]. Biodata form the cornerstone of both discovery and application and are crucial to biotechnology modernization efforts in medicine. Such practices are becoming more widely integrated within medical research and practices focal to the care of US' government personnel (e.g. in the Department of Defense, and intelligence community). However, for both the general population, and key government personnel (e.g. those affected with AHIs), there is risk - if not clear and present threat - that their PHI may be targeted by nefarious actors in ways that directly threaten their health as relevant to their missional effectiveness in national security.

Human biodata are inherently vulnerable to purloinment or corruption and thus may evidently put particular individuals or groups at risk. Thus, while sharing biodata - for diagnostics and development of therapeutics is encouraged, a dilemma arises as policymakers face the challenge of balancing data sharing and the need for ever more ardent protective controls. Traditional biosecurity policies have not adequately addressed these information risks - requiring the need for a novel and specific dimension of biosecurity which has been termed "digital biosecurity" or "cyberbiosecurity" [25].

The growing corpus of digital tools, inclusive of biodesign software applications, network analysis for clinical diagnostics, meta-analyses of digital imaging, and automated medical instrumentation, are certainly vulnerable, at least in concept to traditional cyber-physical risks; which usually involve malicious manipulation of digital systems at both the individual and industrial level [26]. At the individual level, corruption of digital data could lead to misdiagnoses, as well as individualized therapeutic technologies' dysfunction. Despite the availability of tools for "de-identifying" (i.e. anonymizing) individual data, advancements in DNA technologies, and molecular and imaging data analytics now make "re-identification" of de-identified data achievable, and this is readily demonstrable through use of biodata, as well as from biometrics from wearable technologies [27]. This may be particularly concerning in national security contexts [28,29].

The establishment of the Bioeconomy Information Sharing and Analysis Center (BIO-ISAC) is a decisive step toward enhancing digital biosecurity. However, human data categorically require additional safeguards. Similar to early antivirus software, digital biosecurity tools must focus on protecting critical biodata, and in the clinical milieu, such data should be clearly delineated. The capability to mine biodata and related information using machine learning and AI further complicates the cyberbiosecurity dilemma, as tools and techniques that are used to help diagnostic effectiveness and efficiency could also be used (by nefarious actors) to incur harms; indeed, such AI could significantly facilitate ability to acquire and manipulate PHI, and could be employed to target particular individuals in non-kinetic and/or kinetic engagements [25,26,28,29].

Sustaining clinical effectiveness, economic efficiency and ethical probity

To date, inconsistent data collection and variable diagnostic protocols across institutions and countries have hindered effective analysis and intervention of AHIs [7]. The economic implications of failing to standardize protocols for AHIs are profound. Without a unified approach, resources of time, effort, personnel and money can be misallocated across multiple investigations, leading to redundant and inchoate testing, inconsistent findings and ineffective, inefficient care. This exacerbates the suffering of affected individuals and can misdirect public health - and national security - efforts, and further amplifies public and biodefense concerns.

A standardized protocol, grounded in precise analyses of metadata, would ensure uniformity in the assessment of clinical signs, symptoms, environmental factors, and potential causative agents. Such a standardized, metadata-based and AI-integrated paradigm would streamline the diagnostic and investigative processes. Certainly, installing such systems and employing these protocols are not without expense. However, we believe that if established and nationally implemented at key sites of AHI evaluation, this approach to uniform data collection methods would facilitate more rapid cross-case analyses, enabling healthcare professionals and policymakers to identify patterns and causal factors more time- and cost-efficiently (see, for example [30]). This standardization would not merely be a technical improvement; rather, we view it as a strategic necessity for ensuring that the data collected are comparable, reliable, and actionable across different cases and locations.

Moreover, we believe that standardized protocols could enhance international collaboration, allowing for the pooling of data across countries and institutions. This would not only improve the robustness of findings but also distribute the financial burden of research and response efforts. Collaborative international research, underpinned by shared standards, could lead to more cost-effective solutions and foster a spirit of global solidarity in addressing AHIs. In an era where healthcare systems are grappling with budget constraints and resource limitations, such economic efficiency is not merely desirable—it is essential.

Ethical probity: Protecting rights and ensuring transparency

While economic efficiency is a critical consideration, it must not come at the expense of ethical principles. The establishment of standardized protocols for AHIs must be guided by a commitment to ethical probity, ensuring that the rights and dignity of affected individuals are protected throughout the investigative and treatment processes. The precision of metadata plays a critical role in safeguarding the integrity of the diagnostic process and subsequent interventions [31]. Inconsistent data can lead to misdiagnoses, inappropriate treatments, and, ultimately, the erosion of trust in medical and governmental institutions. We argue that standardization thus becomes a matter of ethical probity, ensuring that individuals affected by these incidents are evaluated and treated based on robust, reproducible evidence rather than conjecture or fragmented information.

The ethical rectitude of such standardization is manifest in threefold ways. First, standardization promotes transparency and accountability. When diagnostic criteria and investigative methods are standardized and publicly documented, it becomes easier to evaluate, scrutinize and verify the integrity of findings. This transparency is crucial in maintaining public trust, particularly given the geopolitical sensitivities surrounding incidents like Havana Syndrome. A standardized approach would mitigate suspicions of bias or manipulation, ensuring that conclusions are based on objective, reproducible evidence.

Second, standardized protocols would help safeguard against the exploitation of AHIs for political or ideological purposes. In the absence of clear, consistent diagnostic criteria, there is a risk that health incidents could be misrepresented or exaggerated to serve specific agendas. By grounding assessments in rigorous, standardized methodologies, we can protect against such distortions and ensure that responses are guided by scientific evidence rather than political expediency.

Finally, the ethical imperative to "do no harm" is inherently supported by standardization. Inconsistent or erroneous diagnoses can lead to inappropriate treatments that may exacerbate patients' conditions or expose them to unnecessary risks. Standardized protocols reduce the likelihood of such outcomes by ensuring that all patients are evaluated using the best available evidence and methods. This not only improves clinical outcomes but also upholds the ethical principle of beneficence, ensuring that interventions are designed to maximize patient well-being.

Conclusion: Integrating Considerations toward an Integrative Approach Forward

The intersection of economic efficiency and ethical probity in the context of AHIs is not merely coincidental; it is synergistic. Efficient resource allocation and ethical integrity are mutually reinforcing, each enhancing the effectiveness and credibility of the other. Establishing standardized, metadata-based protocols for the assessment of AHIs could enable both cost-effective solutions and ethically sound practices. To implement such protocols effectively, a multi-disciplinary approach is essential. Collaboration among medical professionals, data scientists, ethicists, and policymakers will be crucial in designing standards that are both scientifically robust and ethically responsible. Furthermore, international cooperation will be vital in ensuring that these protocols are globally applicable and that findings are shared across borders to facilitate comprehensive understanding and response.

In conclusion, the anomalous health incidents associated with Havana Syndrome present a complex challenge that demands economic prudence and ethical rigor. By embracing standardized, metadata-driven protocols, we can ensure that our responses to these incidents are cost-effective and morally sound, ultimately protecting the health and dignity of those affected while fostering greater international cooperation and trust.

Disclaimer

The views and opinions expressed in this manuscript are those of the authors, and do not necessarily reflect those of the National Defense University, United States Department of Defense, or those organizations and institutions that support the authors' work.

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