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Red Hill Registry: Review of Jet Fuel Exposure Related Syndromes and Potential Long-Term Effects

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RED HILL
REGISTRY

Introduction

Learning Objectives:

1. Describe the November 20, 2021 Red Hill water crisis.
2. Compare reported symptoms following JP-5 jet fuel exposure with clinically recognized syndromes.
3. Explain the importance of longitudinal health data collection following environmental exposure events.

Problem: Reported symptoms from those exposed during the Red Hill water crisis spanned multiple body systems; many reported symptoms lasting longer than 30 days. **Currently, there is no recognized clinical syndrome for this type of exposure.**

The Gap: Current evidence on health outcomes associated with jet fuel exposure is primarily based on inhalation and dermal exposures among men of working age. Occupational studies conducted thus far have **not distinguished between pre- or post-combustion exposures, ultimately limiting the ability to attribute toxicological outcomes to specific forms of the fuel** and their unique chemical compositions.¹ The Red Hill exposure involved **ingestion as an exposure route**, an area with significantly limited research. In the ACE investigations, 80% of respondents reported symptoms that persist beyond 30 days and 55% reported worsening of pre-existing conditions following exposure.²⁻⁴ The Red Hill community experienced prolonged exposure through multiple pathways, making it complex and difficult to characterize, and also difficult to associate exposure with clinical outcomes or syndromes. This preliminary analysis aims to lay the groundwork for identifying whether a diagnostic framework or ICD-10 diagnostic code may be needed to support care for those exposed.

Red Hill Water Crisis

The Red Hill Bulk Fuel Storage Facility is a massive underground complex of 20 steel-lined tanks drilled into the side of a mountain ridge, resting 100 feet above Oahu's sole-source aquifer. Constructed during World War II to store up to **250 million gallons of fuel**, the facility supplied the U.S. Navy's Pacific Fleet across the region.

Since its construction, **multiple spills have been documented**, raising concerns about aging infrastructure and risks to human health and the surrounding environment. According to the U.S. Environmental Protection Agency (EPA), an unknown amount of fuel has been released into the environment over the lifetime of the facility. These releases have caused alarm from residents, health officials, and community leaders.

In November 2021, thousands of gallons of JP-5 contaminated the Navy water system. Exposed families reported health impacts affecting nearly every bodily system, prompting widespread calls for the permanent closure and remediation of the site and the development of an independent health registry.

93,000⁵
People
Exposed

JP-5 is a kerosene-based jet fuel composed of hundreds of hydrocarbons as well as several additives. In drinking water, it is measured as total petroleum hydrocarbons.

Figure 1: Map of the Navy's Water System Flushing Zones. (<https://go.hawaii.edu/qbi>)



Presentation of Symptoms from Literature Review

Table 1. Comparison of symptoms reported following the Red Hill water crisis and reported symptoms from literature review of selected syndromes.

Body System	Symptom	1-3 ACE Investigation ²⁻⁴	Gulf War Illness ^{6,7}	Long COVID ⁸⁻¹⁰	ME/CFS ¹¹
Neurological	Headache	✓	✓	✓	✓
	Fatigue	✓	✓	✓	✓
	Insomnia	✓	✓	✓	✓
	Dizziness/Vertigo	✓	—	✓	✓
	Memory issues	✓	✓	✓	✓
	Difficulty concentrating	✓	✓	✓	✓
	Lethargy	✓	—	✓	—
Behavioral	Mood changes	✓	✓	✓	✓
	Agitation	✓	✓	✓	✓
Gastrointestinal	Nausea	✓	✓	—	✓
	Diarrhea	✓	✓	✓	✓
	Vomiting	✓	✓	—	—
	Abdominal discomfort	✓	✓	—	—
Integumentary	Skin rashes	✓	✓	—	—
Muscular	Muscle aches	✓	✓	✓	✓
	Joint pain	✓	✓	✓	✓
Respiratory	Shortness of breath	✓	✓	✓	—

- Check marks on Table 1 represent diagnostic criteria from ICD-10 codes as well as symptoms identified in literature review.
- Syndromes and their symptoms were cataloged by body system and binary-coded across sources (0 = absent, 1 = present) to identify potential patterns.
- ICD-10 diagnostic criteria were cross-referenced against these clusters to confirm clinical diagnostic criteria and identify shared symptoms.
- Overlapping symptoms were flagged to identify clustering patterns and were then narrowed down to the most comparable syndromes. This process included self-reported and military electronic health record data from the Agency for Toxic Substance and Disease Registry (ATSDR) first, second and third Assessment of Chemical Exposure (ACE) investigations along with Gulf War Illness (GWI), myalgic encephalomyelitis/chronic fatigue syndrome (ME/CFS), and Long COVID.

Methods

Literature Search

- Review of secondary literature included searches for systematic reviews, meta-analyses, scoping reviews, and toxicological profiles.
- No publication year restrictions were applied.
- Search terms targeted syndromes potentially related to toxic or other exposures to identify symptoms and diagnostic criteria.
- To ensure validity and meet scientific standards, eligible publications were restricted to those that underwent a peer-review process.

Red Hill Registry Questionnaire

- Adults (18 years or older) who self-identified as living, working, attending school or visiting the Red Hill water line during November 20, 2021, to March 18, 2022, received and completed the Baseline Questionnaire.
- The Baseline Questionnaire includes questions about demographics, military affiliation, exposure behaviors, health, and residential history.
- The health section in the Baseline Questionnaire asks detailed questions on general symptoms, as well as frequency and duration. It also includes questions about new or worsening conditions.

Data Analysis (n=420)

- A latent class analysis (using R packages poLCA) was conducted to identify unobserved (latent) subgroups based on symptoms experienced among the Red Hill Registry participants. The Bayesian Information Criterion (BIC) was used to determine the optimal number of latent classes.
- Participants were grouped into three homogeneous latent classes based on similarities in their symptom-response patterns. The conditional probability of each symptom in each class was estimated and illustrated in the figures below.

Latent Class Analysis

Figure 2: Latent Class Analysis of Current Adult Baseline Questionnaire Participants by Probability of Symptoms in Each Class.

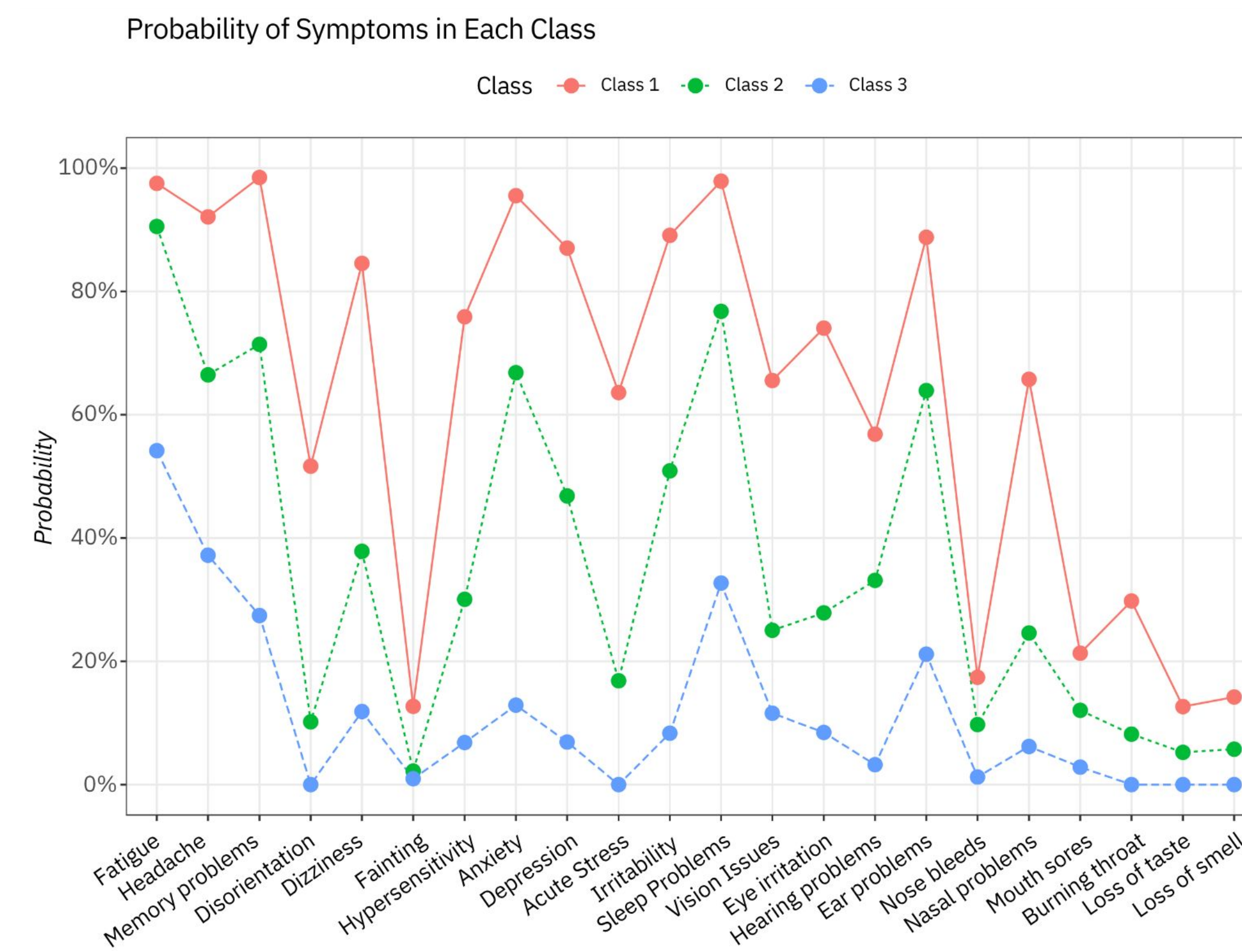


Figure 2 illustrates the Red Hill Registry adult Baseline Questionnaire participants population (n =420) categorized into three distinct classes. Individuals were grouped into three classes based on their clustering patterns of reported symptoms using the latent class analysis code in R. **Class 1 (n=124):** 'severe' symptom presentation cluster of participants reporting the most symptoms overall. **Class 2 (n=202):** participants who had 'moderate' symptom presentation reporting the average amount of symptoms. **Class 3 (n=94):** participants with 'mild' symptom presentation reporting the least symptoms overall. The symptoms seen in all three classes with the highest probability of occurrence on average include **fatigue (~81%), sleep problems (~69%), headache (~65%), memory problems (~65%), anxiety (~59%), and ear problems (~58%).**

Figure 3 (n=420) illustrates overall population proportions along with the probability of specific symptoms reported per class. **Class 1** represents ~29% of the participants and demonstrates the highest probabilities across most symptoms. **Class 2** represents the largest group, ~47%, of participants. **Class 3** represents ~23% of the participants.

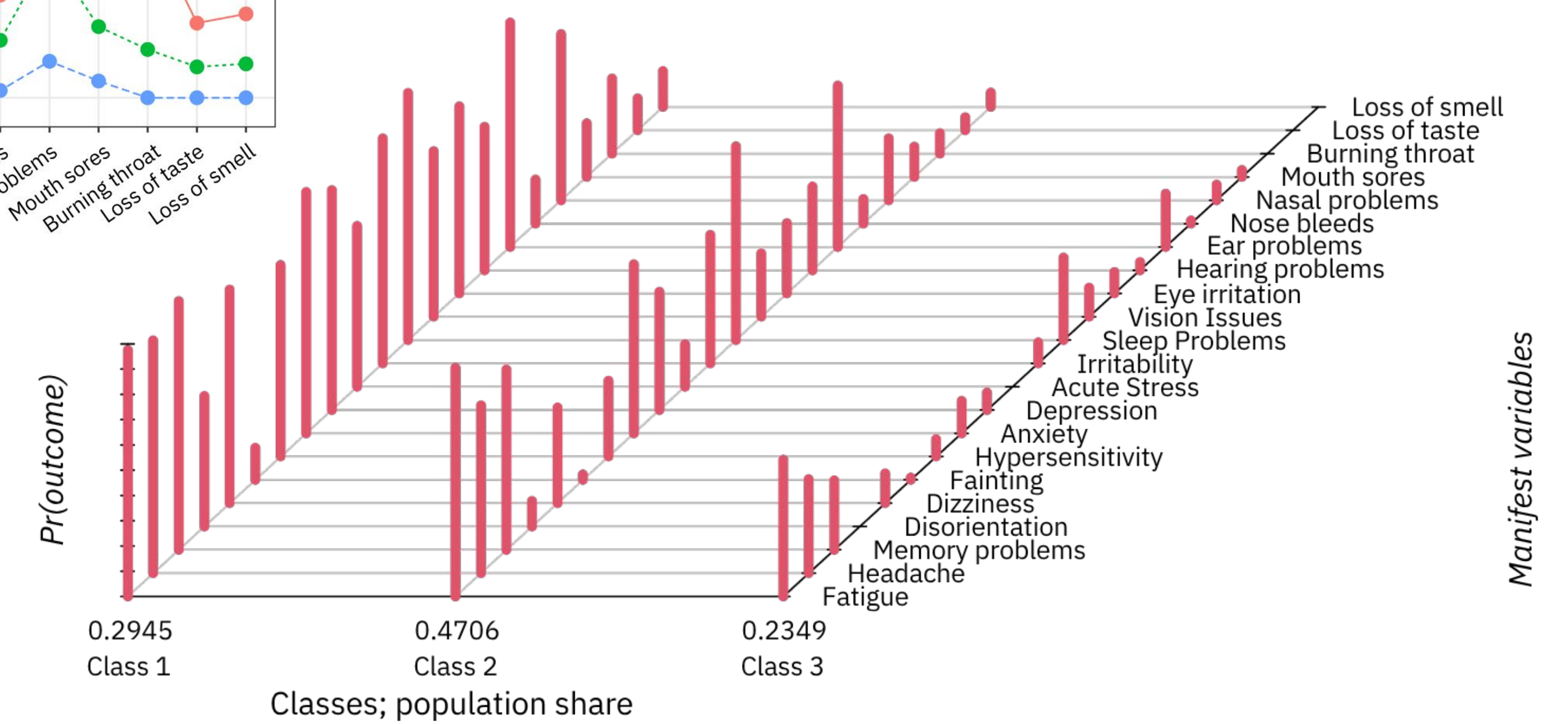


Figure 3: Latent Class Analysis of Adult Baseline Questionnaire Participants by Class.

Discussion

Fatigue, sleep problems, headache, memory problems, anxiety, and ear problems were the symptoms with the highest probability within each of the three classes and overall. Thus, these symptoms may represent central features of participants' reported experiences following exposure. **As seen in Table 1, these symptoms align with the literature on the compared syndromes and ACE investigations, supporting our comparative preliminary findings.**

By comparing reported symptom patterns with clinically recognized syndromes and relevant ICD-10 classifications, this analysis aims to identify preliminary associations between symptoms reported by Red Hill Registry participants and symptoms of established syndromes. Although these patterns do not establish a diagnosis or causal relationship, they may provide a foundation for future framework development and research to evaluate potential syndrome-like symptom clusters. **Establishing a diagnostic criteria and/or ICD-10 code would support long-term clinical care and guidance.** It should also be noted that these preliminary findings may be subject to potential bias, as participants in this dataset were some of the first to join the registry and may be subject to selection bias (may have more severe health impacts). Due to small population size, the statistical power is limited and there is an elevated risk of distortion.

Future research includes developing an individual-level exposure metric that can be used to further refine this latent class analysis. As enrollment in the Red Hill Registry grows, a clearer understanding of the community's health outcomes and symptom patterns may emerge.

References:
<https://go.hawaii.edu/R38>



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