The Role of the Gut Microbiome on Submariner Health and Performance during a Seven-Month Deployment

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Introduction

Submariners experience unique challenges, including a limited diet, altered circadian rhythm, interrupted sleep, stress, a lack of exercise, and a lack of vitamin D via sunlight. These challenges can disrupt the microbiome, causing poorer health outcomes (such as obesity, metabolic syndrome, impaired cognitive performance, and mental health issues). Could prolonged submarine deployment degrade health through adverse effects on the microbiome?

Methods

This study follows up a recently published submarine microbiome study (Liechty et al. 2026, *Microbiology Spectrum* doi:10.1128/spectrum.03059-25). This study includes more measures over a longer period of deployment.

- Samples and surveys were collected from 30 submariners before, during & after deployment.
- See figure below for sampling timeline and complete list of collected metrics.
- The following measures will be discussed in this poster:

Stool Samples

- DNA was extracted from stool and the 16S rRNA gene was amplified and sequenced to profile the microbiome.
- Fecal short-chain fatty acid abundances were profiled through mass spectrometry.

Blood Samples

- Blood samples were taken to measure the level of metabolomic, immune, inflammatory, and other markers.
- Markers were quantified through either enzyme-linked immunosorbent assays (ELISA) or Vitros assays.

Profile of Mood State (POMS)

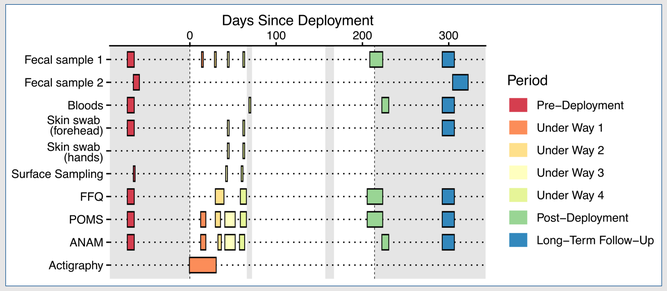
- Mood questionnaire graded on a 5-point scale.
- The raw scores were combined to score general mood states and an overall score of total mood disturbance.

Food Frequency Questionnaire (FFQ)

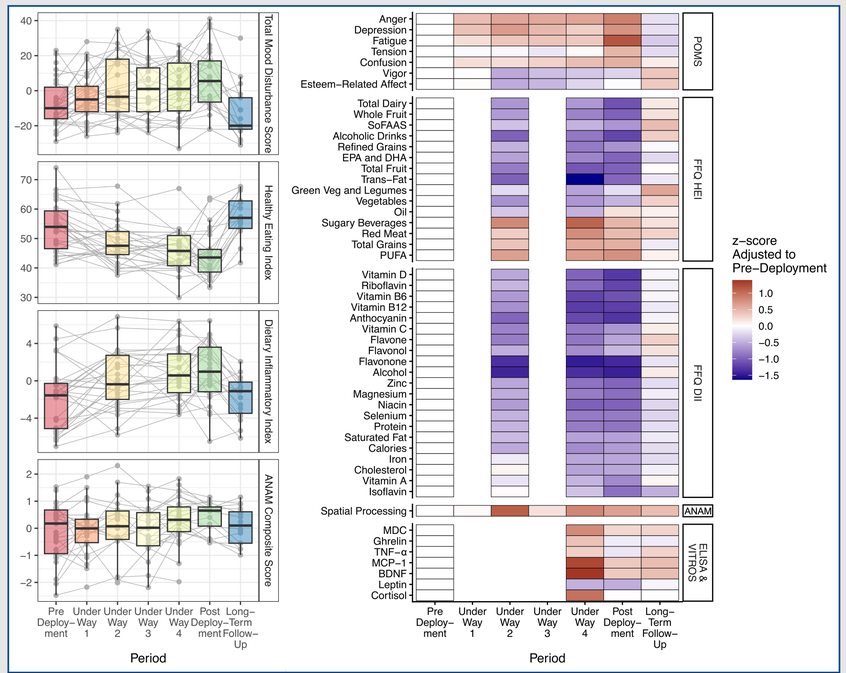
- Questionnaire about the frequency of eating various foods.
- Foods were categorized and quantified on two scales:
  - **Healthy Eating Index (HEI)** – A measure of diet quality determining how well diet adhered to established standards
  - **Dietary Inflammatory Index (DII)** – a measure for scoring the effect of diet on inflammation

Automated Neuropsychological Assessment Metrics (ANAM)

- a computer-based cognitive screening tool designed to evaluate the speed and accuracy of attention, memory, processing speed, and decision-making.



Deployment effects on mood, diet, biomarkers, and cognition



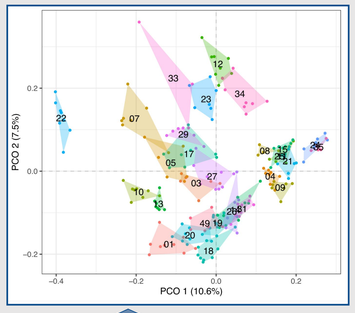
Composite scores shifted during deployment

- The overall mood disturbance increased during deployment but recovered long-term ($P < 0.05$).
- Diet decreased in quality (HEI) and increased in foods associated with inflammation (DII) during deployment ($P < 0.05$).
- Performance on the ANAM cognitive test were not significantly impacted during deployment.

Individual components shifted during deployment

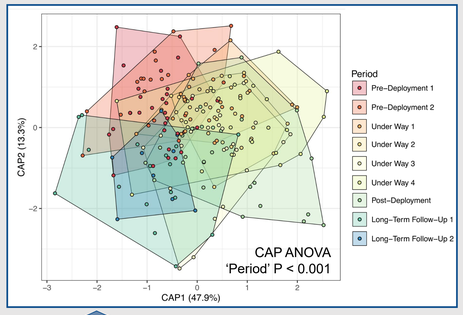
- All depicted markers in the figure above significantly increased or decreased during deployment ($P_{adj} < 0.05$).
- While overall calories decreased during deployment, the food groups most depleted during deployment includes fruits, dairy, and associated nutrients.
- Various immune markers increased during deployment. Ghrelin (hunger-associated) and Cortisol (stress-associated) also increased.

Deployment effects on the microbiome



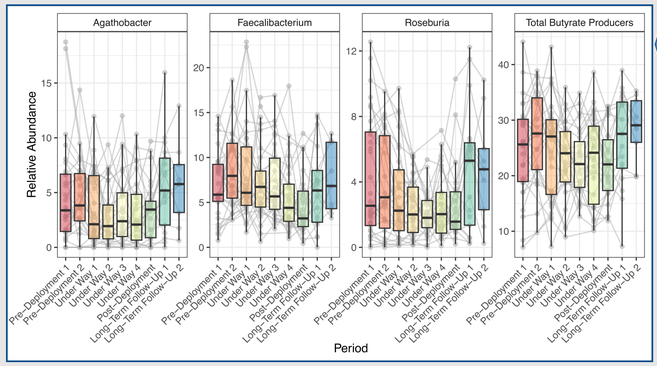
The microbiome was shaped by inter-participant variation

- In the above Principal Coordinate Analysis (PCoA), each dot represents the microbiome composition of one sample, with closer dots having a more similar composition. Samples from each participant are contained within a polygon.
- Microbiome composition was largely affected by the individual participant and maintained a unique signature during deployment.



The microbiome was affected by deployment

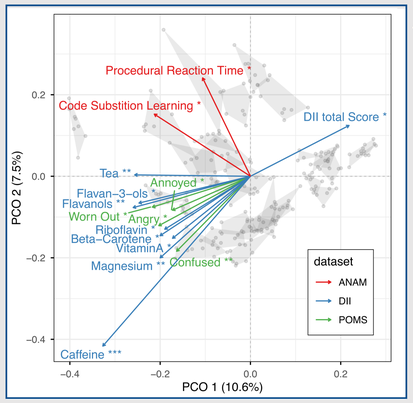
- Controlling for 'participant' in a Constrained PCoA (CAP), deployment period significantly impacted the microbiome.
- While the 'deployed' and 'not deployed' periods separate on the x-axis, the 'pre-deployment' and 'long-term follow-up' periods separate on the y-axis, indicating deployment has a long-term impact on the microbiome.



Butyrate-producing microbes decreased during deployment

- Various taxonomies associated with butyrate production (including *Agathobacter, Faecalibacterium,* and *Roseburia)* decreased during deployment ($P_{adj} < 0.05$).
- The total relative abundance of butyrate producers was predicted and significantly decrease during deployment ($P_{adj} < 0.05$).
- Reduced butyrate production could affect immunity, mood, and fatigue.

Correlations between the microbiome and mood and diet



Various measures correlate with microbiome structure

- Components of the ANAM, DII, and POMS surveys significantly correlated with microbiome composition ($P_{adj} < 0.05$).
- These correlations identify potential drivers of microbial diversity, as well as microbial compositions that affect mood and performance (POMS and ANAM score components).

Various measures correlate with butyrate producers

- Various aspects of DII and POMS correlated significantly with microbial taxa ($P_{adj} < 0.05$).
- Negative correlations with total mood disturbance, depression, and fatigue indicate that mitigating the loss of these microbes could reduce mood disturbance while deployed.
- Positive correlations with aspects of DII indicate potential nutritional interventions that could increase butyrate producers.

		Agathobacter	*Faecalibacterium*	*Roseburia*
POMS	pos	• Esteem-related affect • Tension	• Esteem-related affect	
POMS	neg	• Total Mood Disturbance • Depression		• Total Mood Disturbance • Anger • Fatigue
DII	pos	• Vitamin B12 • Flavonone • Vitamin D	• Beta-Carotene • Flavonone • Vitamin C	• Iron • MUFAs • Protein • Selenium • Thiamin • Vitamin A
DII	neg		• Flavan-3-ol • Flavonol	

Conclusions

- Diet decreased in quality, mood disturbance increased, and various inflammation-associated biomarkers increased during submarine deployment. These changes could impact mission readiness.
- Taxa associated with butyrate production decreased during deployment. Butyrate is essential for maintaining a strong intestinal barrier, reducing inflammation, and regulating the immune system, and the change in the gut microbiome could contribute to the observed changes in inflammation markers, mood decrement, and fatigue.
- Butyrate-producing taxa significantly correlated with mood, and nutrient components. These correlations provide targets that could lead to the development of microbial or dietary interventions that would better prepare submariners for deployment by increasing their resiliency and mitigate the observed decrements in mood and fatigue.

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